

## Direct EPP effects on the middle atmosphere

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Energetic precipitating particles (EPPs) can cause significant direct constituent changes in the mesosphere and stratosphere (middle atmosphere) during certain periods. Both protons and electrons can influence the polar middle atmosphere through ionization and dissociation processes. EPPs can enhance  $\text{HO}_x$  ( $\text{H}$ ,  $\text{OH}$ ,  $\text{HO}_2$ ) through the formation of positive ions followed by complex ion chemistry and  $\text{NO}_x$  ( $\text{N}$ ,  $\text{NO}$ ,  $\text{NO}_2$ ) through the dissociation of molecular nitrogen.

The  $\text{HO}_x$  increases result in direct ozone destruction in the mesosphere and upper stratosphere via several catalytic loss cycles. Such middle atmospheric  $\text{HO}_x$ -caused ozone loss is rather short-lived due to the relatively short lifetime (hours) of the  $\text{HO}_x$  constituents. The  $\text{NO}_x$  family has a considerably longer lifetime than the  $\text{HO}_x$  family and can also lead to catalytic ozone destruction. EPP-caused enhancements of the  $\text{NO}_x$  family can affect ozone directly, if produced in the stratosphere. Ozone decreases from the EPPs lead to a reduction in atmospheric heating and, subsequent atmospheric cooling. Conversely, EPPs can cause direct atmospheric heating through Joule heating.

Measured  $\text{HO}_x$  constituents  $\text{OH}$  and  $\text{HO}_2$  showed increases due to solar protons. Observed  $\text{NO}_x$  constituents  $\text{NO}$  and  $\text{NO}_2$  were enhanced due to both solar protons and precipitating electrons. Other hydrogen- and nitrogen-containing constituents were also measured to be directly influenced by EPPs, including  $\text{N}_2\text{O}$ ,  $\text{HNO}_3$ ,  $\text{HO}_2\text{NO}_2$ ,  $\text{N}_2\text{O}_5$ ,  $\text{H}_2\text{O}_2$ ,  $\text{ClONO}_2$ ,  $\text{HCl}$ , and  $\text{HOCl}$ . Observed constituents  $\text{ClO}$  and  $\text{CO}$  were directly affected by EPPs as well. Many measurements indicated significant direct ozone decreases.

A significant number of satellites housed instruments, which observed direct EPP-caused atmospheric effects, including Nimbus 4 (BUV), Nimbus 7 (SBUV), several NOAA platforms (SBUV/2), SME, UARS (HALOE, CLAES), SCISAT-1 (ACE-FTS), Odin (OSIRIS), Envisat-1 (GOMOS, MIPAS, SCIAMACHY), and Aura (MLS). Measurements by rockets and ground-based radar also indicated EPP direct impacts. Atmospheric models have been used with some success in predicting the direct EPP impacts on the mesosphere and stratosphere. A review of the observed direct effects of EPP on the middle atmosphere will be given in this presentation.